Research Interests and Plans
L. Coney

My research is at the forefront of particle physics and accelerator physics. I began my career in high energy physics (HEP) on the D∅ experiment[1] at the Fermi National Accelerator Laboratory (Fermilab). D∅ is an international collaboration of physicists who study fundamental interactions of protons and antiprotons in collisions at the world's highest energy accelerator, the Tevatron. I then became involved in MiniBooNE, the Hadron Production Experiment (HARP) at CERN, and Neutrino Factory R&D. MiniBooNE is an experiment at Fermilab conducting a search for neutrino oscillations, while HARP measures particle production in proton-nucleus collisions. My path has gradually migrated from that of a traditional particle physicist to become a bridge between HEP and accelerator physics. I plan to continue this exploration of accelerator physics both as a support structure for HEP, and as a separate field with interesting challenges of its own. Because I combine interests in both accelerators and particle physics, I believe I will bring a unique perspective to your university.

On the D∅ experiment, my thesis was on the diffractive production of W and Z bosons in proton-antiproton collisions. This was the first observation of diffractively produced Z bosons and the most significant measurement yet of diffractively produced W bosons [2]. While I was a graduate student, I became interested in the bigger picture at Fermilab. I began to understand the rich complexity of the accelerators providing beam to the collider experiments and became more interested in this aspect of particle physics. As a graduate student and member of the Fermilab UEC, I organized a series of seminars on accelerator physics for the graduate student population of FNAL. I believe it is important for those working on particle physics experiments to understand the challenges involved in providing beams for their experiments.

My growing interest in accelerator physics enabled me to transition naturally into a postdoc with Columbia University on the Neutrino Factory [3,4,5]. The Neutrino Factory is a machine designed to produce a large number of low energy muons which are then manipulated into an appropriately configured muon beam, accelerated to a high energy, and injected into a storage ring. There they decay to provide a very intense and well understood neutrino beam to experiments [6]. I decided to focus on the "front end" of the neutrino factory which includes hadron production from a target using a high intensity proton beam. This is the foundation upon which all of the other systems, including pion collection, muon cooling, and muon acceleration will depend.

HARP (the Hadron Production Experiment [7,8]) is designed to measure pion and kaon production cross sections in proton-nucleus collisions over the momentum range of 1.5-15 Gev/c. Data were recorded in 2001-02 on a number of different nuclei ranging from hydrogen to lead. The design of pion capture systems depends critically on accurate knowledge of primary pion momentum distributions in order to maximize pion acceptance and minimize costs. Therefore, HARP results will help determine ideal targetry and beam settings for the neutrino factory [8]. In addition to its relevance to the neutrino factory, the MiniBooNE experiment [9] has collaborated with the HARP group to directly measure meson production rates from the MiniBooNE target. With Columbia University graduate students Michel Sorel and David Schmitz, I took data at HARP using a beam momentum of 8.9 GeV/c, specifically tuned to match the Fermilab Booster beam. This beam was incident upon a 5% interaction length (λ) beryllium (Be) disk target, and both 50% and 100% λ replicas of the MiniBooNE target.

At the present time, we are preparing to finalize and publish the inclusive charged pion cross section measurement for the 5% λ Be target using the forward portion of the HARP detector. This analysis utilizes the three particle identification detectors in HARP: a Cerenkov detector with a pion threshold of 2.6 GeV/c, a time-of-flight system, and a calorimeter system which separates electrons from hadrons. This omits the HARP TPC which surrounds the target, but covers nearly all of the kinematic range of pion momentum and angle which is important to MiniBooNE. This will reduce the systematic uncertainties on the neutrino flux at MiniBooNE. I am currently working on the analysis of the thicker MiniBooNE replica targets to measure any effects on the cross section due to pion reinteraction within the target, thereby further constraining the ν_μ flux. Additionally, we will use the HARP data to measure kaon production from the MiniBooNE target in order to constrain the background in the beam due to intrinsic ν_e from kaon decay. I have also worked on a parallel analysis to measure the inclusive pion cross sections for a 5% λ aluminum target with a 12.9 GeV/c beam [10]. This target and beam setting was designed to mimic that of the K2K experiment. This result was the first to be published from HARP, and will be used to significantly reduce the K2K systematic error stemming from the uncertainty on the far/near neutrino flux ratio [11].

As part of the HARP collaboration, I have been heavily involved in several of the software efforts. I have worked extensively to develop the system for remote-site HARP analyses at Fermilab, Los Alamos National Laboratory, and several universities in Europe and Japan. I was responsible for creating accurate material geometries for the HARP Geant4-based simulation code, and have made modifications to the analysis code in order to accommodate a change in data base structure from Objectivity to Oracle. While these software efforts have been vital to the functioning of the experiment, I am very interested in extracting the exciting physics results from HARP. To this end, I became co-leader of the HARP Production Group and was responsible for providing accurate data and Monte Carlo samples used by the entire experiment for both calibration and analysis purposes. In this role I coordinated the efforts of people on three continents while ensuring data quality. I was also responsible for tuning and validating the simulation of the HARP threshold Cerenkov detector. I have also worked with graduate student David Schmitz to develop a particle identification strategy for the HARP cross section analysis. In total, our group has been responsible for a large part of the effort in two of the three PID detectors used in the HARP analyses.

In addition to my efforts on HARP, I have also worked on several projects involving the Fermilab Booster, an 8 GeV rapid-cycling proton synchrotron. This machine is a crucial element of the Fermilab accelerator chain and provides beam to many users. As a rapid-cycling high intensity proton synchrotron, the Booster provides an ideal environment in which to learn about challenges that arise due to running conditions which will be seen in the front end of the neutrino factory.

The ability to monitor and control the many orbit, RF, and magnet parameters during the rapid acceleration phase of high intensity proton machines is central to understanding their performance. I have worked on a diagnostic system called the Booster Monitor, a recently developed tool which constantly monitors ramped devices within the Booster. It enables the user to learn about the level of stability in Booster devices and determine correlations between individual device performance and overall machine performance. With undergraduates Chandra Jacobs and Ami Choi, we have integrated the Booster Monitor into a long term Datalogger system at Fermilab. This allows reliable analysis of Booster performance over long periods of time. The Booster Monitor and Datalogger programs are used to analyze ramped device performance while the Booster provides beam to the MiniBooNE experiment. I have also worked with the FNAL Booster Group and Columbia University graduate student Jocelyn Monroe on a project to develop, install, and test dipole correctors to reduce uncontrolled beam motion due to dipole field errors. These ramped correctors have successfully controlled the Booster beam orbit throughout the full acceleration cycle resulting in significantly lower beam losses near sensitive equipment [12]. Working with the same group, I have also explored resonant extraction of beam halo. This method tune-shifts the beam through a resonance such that the halo is extracted into a collimator system while leaving the beam core intact.

My work on the front end of the neutrino factory segues nicely into MICE [13], the Muon Ionization Cooling Experiment, and recently proposed MANX, the 6D Muon and Neutrino Experiment [14]. In order to optimize neutrino factory performance, a very intense muon beam is needed. Since the muons come from a cloud of pions produced by hitting a target with an intense proton beam, it is necessary to compress the phase space of the muon beam, or “cool” the beam, before the acceleration and storage phase of the neutrino factory. Due to the short muon lifetime, traditional techniques like stochastic cooling are not viable. Ionization cooling [15, 16, 17], where the beam is passed through several liquid hydrogen absorbers followed by accelerating RF cavities, has been proposed as an alternative cooling method [18]. In this method, the beam loses both longitudinal and transverse momentum in the absorbers, but only longitudinal momentum is restored in the RF cavities. When repeated, this reduces the angular spread of the beam, thereby reducing the transverse emittance and cooling the beam. In order to keep the muon beam divergence in the storage ring low enough to ensure a focused neutrino beam, roughly a factor of 10 reduction in transverse emittance (in both dimensions) must be accomplished through cooling [4,5]. The MICE experiment has been proposed to test the ionization cooling method. It will begin running at Rutherford Appleton Lab in late 2007, and will progress in stages until it ultimately represents a full lattice section of the cooling portion of the neutrino factory. MICE will reduce the beam transverse emittance by over 10%, and spectrometers using standard particle physics techniques will measure beam emittance reduction with an absolute precision of +/- 0.1% [13]. MICE will also provide a test of the challenges involved in operating a cooling channel including a high radiation environment, multiple scattering in the absorbers, and operating RF cavities close to liquid hydrogen containers within a magnetic field.

Where MICE is designed to demonstrate ionization cooling and test a full neutrino factory cooling lattice section, MANX proposes to demonstrate 6D cooling in preparation for a muon collider. Such a collider demands a great deal more cooling than current neutrino factory designs provide, and in fact requires longitudinal cooling in addition to the transverse cooling addressed by MICE. MANX plans to use a new superconducting magnet called a Helical Cooling Channel (HCC) filled with an absorber such as liquid hydrogen or helium to produce an astonishing 500% cooling factor of a 300 MeV/c muon beam [14]. The proposed technique takes advantage of beam dynamics through the continuous absorber to reduce the momentum spread of the muon beam. There are several similarities between these two experiments, and the particle spectrometers, particle ID detectors, and data analysis techniques from MICE could potentially be used in MANX depending on the experimental timelines involved. This is a very exciting new experiment which could bring a muon collider out of the realm of fantasy and enable it to seriously contend as an energy frontier machine.

I am in contact with the spokespersons of MICE and am discussing a number of areas where I could contribute. Fortunately, MICE is still at the stage where not all interesting projects are "taken," and MANX has only recently been proposed. There is still room for me to make a very visible contribution to these experiments on a short time-scale. These projects involve hardware, software, and analysis, are practical to do in a university environment, will involve students, and are of an ideal scale for an NSF CAREER grant. I am very excited about this fantastic opportunity to continue my work within particle and accelerator physics.

References

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